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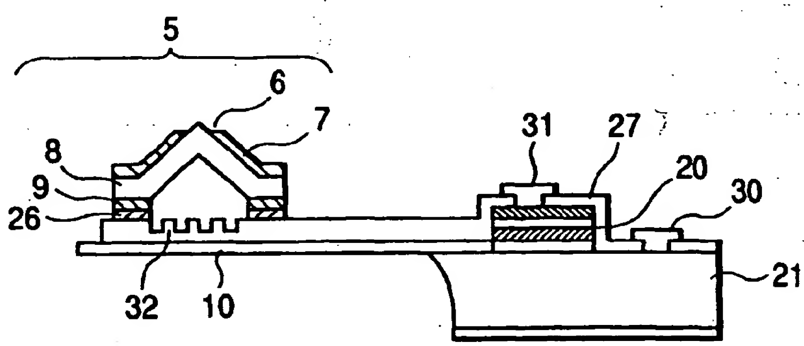
(54) Probe with tip having micro aperture for detecting or irradiating light, near-field optical microscope, recording/reproduction apparatus, and exposure apparatus using the probe, and method of manufacturing the probe

(57) A probe for detecting or irradiating light includes a displaceable support member on a substrate, a tip formed on the support member, and a bonding layer for bonding the tip onto the support member. The tip has a micro aperture. When a light-shielding layer is further formed on a surface of the tip, the micro aperture is formed on the light-shielding layer. The tip consists of a light transmission material.

FIG. 1



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a bonding layer for bonding the tip onto the support member.

In order to achieve the above object, there is also provided a near-field optical microscope comprising the above-mentioned probe.

In order to achieve the above object, there is also provided a recording/reproduction apparatus comprising the above-mentioned probe.

In order to achieve the above object, there is also provided an exposure apparatus comprising the above-mentioned probe.

In order to achieve the above object, there is also provided a method of manufacturing a probe for detecting or irradiating light, comprising the steps of:

forming a recess portion on a surface of a first substrate;
forming a peeling layer on the first substrate including the recess portion;
forming a tip consisting of a light transmission material on the peeling layer including the recess portion;
forming a bonding layer on a second substrate;
bonding and transferring the tip onto the bonding layer; and
forming a support member for supporting the tip by removing a portion of the second substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view showing a probe according to the first embodiment of the present invention;
Fig. 2A is a top view showing the probe of the first embodiment, Fig. 2B is a sectional view taken along a line 2B - 2B in Fig. 2A, and Fig. 2C is a sectional view taken along a line 2C - 2C in Fig. 2A;
Figs. 3A, 3B, 3C, 3D, 3E, 3F and 3G are sectional views showing the manufacturing processes of the probe of the first embodiment;
Fig. 4 is a view showing the arrangement of a surface observation apparatus using the probe of the first embodiment;
Fig. 5 is a sectional view showing a probe according to the second embodiment of the present invention;
Figs. 6A, 6B, 6C, 6D, 6E, 6F and 6G are sectional views showing the manufacturing processes of the probe of the second embodiment;
Fig. 7 is a view showing the arrangement of a surface observation apparatus using the probe of the second embodiment;
Fig. 8 is a sectional view showing a probe according to the third embodiment of the present invention;
Fig. 9A is a top view showing the probe of the third embodiment, and Fig. 9B is a sectional view taken along a line 9B - 9B in Fig. 9A;
Figs. 10A, 10B, 10C, 10D, 10E, 10F and 10G are sectional views showing the manufacturing processes of the probe of the third embodiment;
Fig. 11 is a view showing the arrangement of a recording/reproduction apparatus using the probe of the third embodiment;
Figs. 12A, 12B, 12C, 12D, 12E and 12F are sectional views showing the manufacturing processes of a probe according to the fourth embodiment of the present invention;
Fig. 13 is a view showing the arrangement of an exposure apparatus using the probe of the fourth embodiment; and
Figs. 14A and 14B are views showing the conventional methods of manufacturing a probe.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The present invention can realize its object with the above-mentioned arrangements.

The present invention will be described in detail hereinafter with reference to the accompanying drawings.

A probe according to the present invention is a probe for detecting or irradiating evanescent light, and comprises an elastic member (support member) 10 formed on a substrate 21, a tip 5 for evanescence formed on the free end portion of the elastic member, a light-receiving element 19 or laser 20, and a waveguide 28 for optically connecting the light-receiving element 19 or laser 20 and the tip 5.

Figs. 3A to 3G are sectional views showing an example of the manufacturing processes of the probe. The manufacturing method will be explained below with reference to Figs. 3A to 3G.

First, a recess portion 3 is formed on the surface of a first substrate 1 consisting of silicon. In order to form such recess portion, a protection layer 2 is formed on the first substrate 1, and a desired portion of the protection layer 2 is patterned by photolithography and etching to expose the silicon. The exposed silicon portion is etched by, e.g., crystallographic axis anisotropic etching, so as to form the recess portion 3. As the protection layer 2, silicon dioxide or silicon nitride may be used.

Silicon is preferably etched by crystallographic axis anisotropic etching since it can form a tip 5 with a sharp distal end. When a potassium hydroxide aqueous solution or the like is used as an etchant, an inverted pyramidal recess portion 3 surrounded by four surfaces equivalent to the (111) face can be formed (see Fig. 3A).

Second, a peeling layer 4 consisting of an oxide is formed on the first substrate 1 including the recess portion 3 (see Fig. 3B).

Since the tip 5 is formed on the peeling layer 4 and is then peeled from the peeling layer 4 in a process after formation of the peeling layer 4, a material that allows easy peeling of the material of the tip 5 must be selected

By executing parallel processing of information using a multi probe that carries a plurality of probes according to the present invention, a surface observation apparatus or recording/reproduction apparatus with a high transfer rate can be provided.

Since the SNOM probe according to the present invention is formed on the elastic cantilever, the magnitude of the contact force between the tip (tip 5) distal end and sample can be controlled to a given value or less while the tip (tip 5) distal end contacts the sample.

For example, let k be the elastic constant of the elastic cantilever, and Δz be the maximum amount of positional variations of the tip distal end in the z-direction. Then, since contact force variations while all tip (tip 5) distal ends contact the surface of the recording medium or sample are represented by $k\Delta z$, the magnitudes of all the contact forces can be controlled to $k\Delta z$ or less by controlling the position between the second substrate 21 and the recording medium or sample in the z-direction. In this fashion, the tip (tip 5) distal end, or the recording medium or sample can be prevented from being destroyed by an excessive contact force applied.

The detailed embodiments of the present invention will be explained below.

[First Embodiment]

The first embodiment is directed to an evanescent light probe and its manufacturing method according to the present invention. Figs. 1 and 2A to 2C show the structure of the probe.

The probe of this embodiment comprises an elastic lever 10 formed on a substrate 21, a tip 5 which is formed on the free end portion of the elastic lever and irradiates evanescent light, a laser 20, and a waveguide 28 for optically connecting the laser 20 and the tip 5.

Figs. 3A to 3G are sectional views showing the manufacturing processes of the evanescent light probe according to this embodiment.

The manufacturing method will be explained below with reference to Figs. 3A to 3G.

A (100) single-crystal silicon wafer was prepared as a first substrate 1.

A 100-nm thick silicon thermal oxide film was formed as a protection layer 2. A desired portion of the protection layer 2 was patterned by photolithography and etching to expose 10-μm^2 silicon.

The silicon exposed from the patterned portion was etched by crystallographic axis anisotropic etching using an aqueous potassium hydroxide solution.

Note that the etching conditions were: a 30% aqueous potassium hydroxide solution was used, and a solution temperature of 90°C and an etching time of 10 min were set.

At this time, a inverted pyramidal recess portion 3 having a depth of about 7 µm and surrounded by four surfaces equivalent to the (111) plane was formed (see Fig. 3A).

The thermal oxide film as the protection layer 2 was then removed by an aqueous solution mixture of hydrogen fluoride and ammonium fluoride ($HF : NH_4F = 1 : 5$). After the removal, the first substrate 1 was washed using a solution mixture of sulfuric acid and hydrogen peroxide heated to 120°C, and a 2% aqueous hydrofluoric acid solution. The first substrate 1 was heated to 1,000°C in an oxygen/hydrogen atmosphere using an oxidization oven to deposit a 500-nm thick silicon dioxide (SiO_2) film serving as a peeling layer 4 (see Fig. 3B).

The film formation for the material of the tip 5 was done. A 0.1-µm thick gold (Au) film was formed by vacuum evaporation to obtain a metal film 7, and a 0.6-µm thick ITO (indium tin oxide) film was formed by sputtering to obtain a light transmission layer 8. These films were then patterned by photolithography and etching. In this case, Au etching used an aqueous solution mixture of KI and I_2, and ITO etching used an aqueous solution mixture of HCl and $FeCl_3$. After patterning, a 0.3-µm thick gold (Au) film was formed again by vacuum evaporation, and was patterned by photolithography and etching to obtain a bonding assist layer 9 (see Fig. 3C).

A 300-µm thick single-crystal n-InP substrate was used as a second substrate 21, and a 1-µm thick n-InP buffer layer 22, a 0.1-µm thick InGaAsP active layer 23, a 1.5-µm thick p-InP cladding layer 24, and a 0.3-µm thick p-InGaAs capping layer 25 were formed in turn on the substrate 21 by MOCVD (metal organic chemical vapor deposition) (see Fig. 3D).

The obtained multilayered structure was patterned and etched by photolithography to form a ridge structure, thus obtaining a laser 20. The wavelength of the laser formed by the above-mentioned method was 1.3 µm. Etching was done by RIBE (reactive ion beam etching) using Cl_2 gas. A 3-µm thick SiO_2 film as a lever material, insulating layer 27, and mask layer 29 was formed on both surfaces of the structure by sputtering. The SiO_2 films on both surfaces were patterned and etched by photolithography to form contact holes, a cantilever structure, and a mask layer 29.

The thickness of the cantilever was 1 µm. A 200-nm thick AuGe film and 300-nm thick Au film were deposited by vacuum evaporation, and were patterned and etched by photolithography to form a bonding layer 26, wiring electrode 33, and output electrode 30 on the substrate side. A 3-µm thick SiO_2 film as a waveguide 28 was deposited by sputtering. The waveguide 28 was then formed by photolithography and etching. The etchant used was an aqueous solution mixture of hydrochloric acid (HCl) and phosphoric acid (H_3PO_4). In this case, the projecting portion of the waveguide formed a secondary diffraction grating. From this grating, light inside the waveguide can be output upward. The waveguide 28 had a height of 2 µm and a width of 5 µm. A 50-nm thick Cr film and 300-nm thick Au film were deposited by vacuum evaporation, and were patterned and etched by photolithography to form an output elec-

ited by vacuum evaporation, and were patterned and etched by photolithography to form a bonding layer 26, wiring electrode 33, and output electrode 30 on the substrate side.

In this case, Au etching used ion milling to taper the waveguide connection portion of the bonding layer.

A 3-μm thick SiO_2 film as a waveguide 28 was deposited by sputtering. The waveguide 28 was then formed by photolithography and etching. The etchant used was an aqueous solution mixture of hydrochloric acid (HCl) and phosphoric acid (H_3PO_4).

The waveguide 28 had a height of 2 μm and a width of 5 μm. A 50-nm thick Cr film and 300-nm thick Au film were deposited by vacuum evaporation, and were patterned and etched by photolithography to form an output electrode 31 of the capping layer (see Fig. 6E).

After the tip 5 on the first substrate 1 and the bonding layer 26 on the second substrate 21 were aligned to face each other, they were brought into contact with each other and were pressurized, thus bonding the tip 5 and the bonding layer 26 (pressure bonding) (Fig. 6F). The first and second substrates 1 and 21 were separated from each other to peel the peeling layer 4 and tip 5 at their interface.

After a protection film was formed on the surface of the second substrate, the n-InP substrate was etched from its rear surface using an aqueous HCl solution to form an SiO_2 cantilever. After the formation of the cantilever, the protection film was removed.

Finally, the tip 5 covered by the metal layer 7 was brought into contact with a metal substrate, and a voltage was applied across the tip 5 and metal substrate via the wiring electrode 33 by a voltage application means. Upon application of the voltage, a micro aperture was formed at the tip distal end portion of the metal layer 7. The diameter of the aperture was about 20 nm (see Fig. 6G).

As shown in Figs. 5 and 6A to 6G, in this embodiment, the micro aperture is formed by forming a metal layer as a light-shielding layer. The structure of this embodiment that guides light detected by the tip toward the light-receiving element does not always require the light-shielding layer. However, the light-shielding layer is preferably arranged since the photodetection resolution can be improved.

Fig. 7 shows the arrangement of an SNOM observation apparatus using the probes of this embodiment. A sample 17 is placed on a transparent substrate on an x-y-z scanner.

Light is irradiated to make an angle that satisfies the total reflection conditions with the surface of the sample 17 from the rear side of the sample 17 via the transparent substrate. At this time, light is not transmitted upward (Fig. 7) through the surface of the sample 17, but evanescent light leaks out through the surface within a very close vicinity 0.1 μm or less from the surface of the sample 17.

When x-y scanning is done while the tip (tip 5) distal ends of a plurality of SNOM probes contact the sample 17, the evanescent light components enter the waveguide 28 via the micro apertures of the SNOM probes, and are detected by the light-receiving element 19. The detected signals are I/V-converted and are input to a multiplexer to obtain multi SNOM signals.

By plotting the magnitudes of such SNOM signals, an SNOM observation image of the sample 17 can be obtained.

[Third Embodiment]

The third embodiment is directed to still another evanescent light probe and its manufacturing method according to the present invention. Figs. 8, 9A and 9B show the structure of the probe.

The probe of this embodiment comprises an elastic lever 10 formed on a substrate 21, an evanescent light tip 5 formed on the free end portion of the elastic lever, a light-receiving element 19, a laser 20, and a waveguide 28 for optically connecting the light-receiving element 19 and laser 20 to the tip 5.

When the laser 20 used in the first embodiment and the light-receiving element 19 used in the second embodiment are connected to the tip (tip), return light of evanescent light irradiated from the tip onto a recording medium 18 can be detected. In this embodiment, a plurality of probes are disposed on the second substrate 21.

Figs. 10A to 10G are sectional views showing the manufacturing processes of the evanescent light probe according to this embodiment.

The manufacturing method will be explained below with reference to Figs. 10A to 10G.

A (100) single-crystal silicon wafer was prepared as a first substrate 1.

A 100-nm thick silicon thermal oxide film was formed as a protection layer 2. A desired portion of the protection layer 2 was patterned by photolithography and etching to expose 10-μm^2 silicon. The silicon exposed from the patterned portion was etched by crystallographic axis anisotropic etching using an aqueous potassium hydroxide solution. Note that the etching conditions were: a 30% aqueous potassium hydroxide solution was used, and a solution temperature of 90°C and an etching time of 10 min were set. At this time, an inverted pyramidal recess portion 3 having a depth of about 7 μm and surrounded by four surfaces equivalent to the (111) plane was formed (see Fig. 10A).

The thermal oxide film as the protection layer 2 was then removed by an aqueous solution mixture of hydrogen fluoride and ammonium fluoride (HF : NH_4F = 1 : 5).

After the removal, the first substrate 1 was washed using a solution mixture of sulfuric acid and hydrogen peroxide heated to 120°C, and a 2% aqueous hydrofluoric acid solution. The first substrate 1 was heated to 1,000°C in an oxygen/hydrogen atmosphere using an oxidization oven to deposit a 500-nm thick sili-

The manufacturing method will be explained below with reference to Figs. 12A to 12F.

Following the same procedures as in the first embodiment, a tip 5 made up of a metal layer 7, light transmission layer 8, and bonding assist layer 9 was formed (see Figs. 12A, 12B, and 12C).

A 200-μm thick single-crystal silicon substrate was prepared as a second substrate 21, and a 300-nm thick silicon dioxide film and 200-nm thick silicon nitride film were deposited on both surfaces of the substrate respectively by thermal oxidation and low-pressure chemical vapor deposition (LPCVD). The silicon nitride film on the surface was patterned to have a lever shape. A 5-nm thick chromium film and 50-nm thick gold film were then deposited and were patterned to form a bonding layer 26 (see Fig. 12D).

After the tip 5 on the first substrate 1 and the bonding layer 26 on the second substrate 21 were aligned to face each other, they were brought into contact with each other and were pressurized, thus bonding the tip 5 and the bonding layer 26 (pressure bonding) (Fig. 12E).

The first and second substrates 1 and 21 were separated from each other to peel the peeling layer 4 and tip 5 at their interface. The silicon dioxide film and silicon nitride film on the rear surface were patterned to form an opening. After a protection film was formed on the surface, the second substrate 21 was etched using an aqueous potassium hydroxide solution, and the silicon dioxide film on the surface was also etched, thus forming a lever 10.

The tip distal end was polished by scanning the sample surface with a load to form a micro aperture having a diameter of about 20 nm on the metal layer 7, thus exposing the light transmission layer 8 therefrom.

Subsequently, a third substrate 119, on which light-emitting elements 116 comprising surface-emission lasers were disposed in a matrix at a position corresponding to the tip 5 on the second substrate 21, was prepared. The third substrate 119 is obtained by forming anodes 123, cathode 124, active layer 125, mirror layers 126, silicon nitride layer 127, and polyimide layer 128 on a gallium arsenide substrate. The anodes 123 are connected to the individual light-emitting elements 116 to independently drive them. The silicon nitride layer 127 is formed to attain insulation of the anode 123. The cathode 124 is a common electrode. When a voltage is applied across the anode 123 and cathode 124, a laser beam produced in the active layer 125 is reflected by the upper and lower mirror layers 126, and is emitted from the upper opening. After the third substrate was prepared, the second and third substrates 21 and 119 were bonded to each other using an epoxy resin 118 after they were aligned so that laser beams coming from the light-emitting elements 116 were directly guided to the tip 5 and the opening (see Fig. 12F).

The multi light probe was manufactured by the above-mentioned processes.

Fig. 13 shows the arrangement of an exposure apparatus using the multi probe of this embodiment. A substrate applied with photoresist is placed on a holder on an x-y-z scanner. The probe of this embodiment is set to oppose the photoresist, and x-y scanning is done while the tip 5 contacts the photoresist. By ON/OFF-controlling evanescent light to be irradiated from the tip 5 onto the photoresist surface, a micropattern can be formed, and high exposure speed can be realized.

This embodiment has exemplified the probe structure that directly guides light coming from each light-emitting element to the tip. Alternatively, as in the second embodiment, a light-receiving element may be formed in place of the light-emitting element, and light detected by the tip may be directly guided to the light-receiving element. In this case, the light-shielding layer with a micro aperture is not always required, as in the second embodiment.

In the above-mentioned embodiments, the tip is supported by the cantilever. However, the present invention is not limited to such specific support structure. For example, a double-supported lever type, torsion lever type, or the like may be used as the support structure. In case of the cantilever type and double-supported lever type, the support member must be an elastic member, but in case of the torsion lever type, the support member is not limited to an elastic member.

Claims

1. A probe for detecting or irradiating light, comprising:

   a displaceable support member supported on a substrate;
   a tip formed on said support member and having a micro aperture; and
   a bonding layer for bonding said tip onto said support member.

2. A probe according to claim 1, further comprising a light-shielding layer formed on a surface of said tip, and
   wherein said micro aperture is formed on said light-shielding layer.

3. A probe according to claim 1, wherein said tip consists of a light transmission material.

4. A probe according to claim 1, further comprising:

   a light-emitting element and/or a light-receiving element formed on said substrate; and
   a waveguide formed between said light-emitting element and/or said light-receiving element, and said tip, and
   wherein a portion of said waveguide is formed on said support member.

FIG. 1

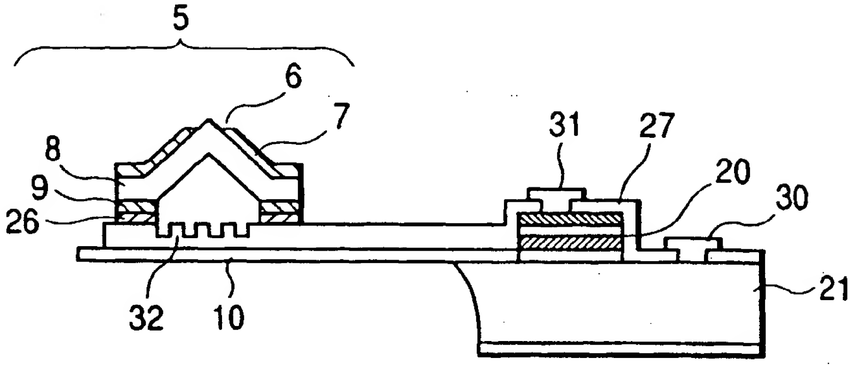


FIG. 2A

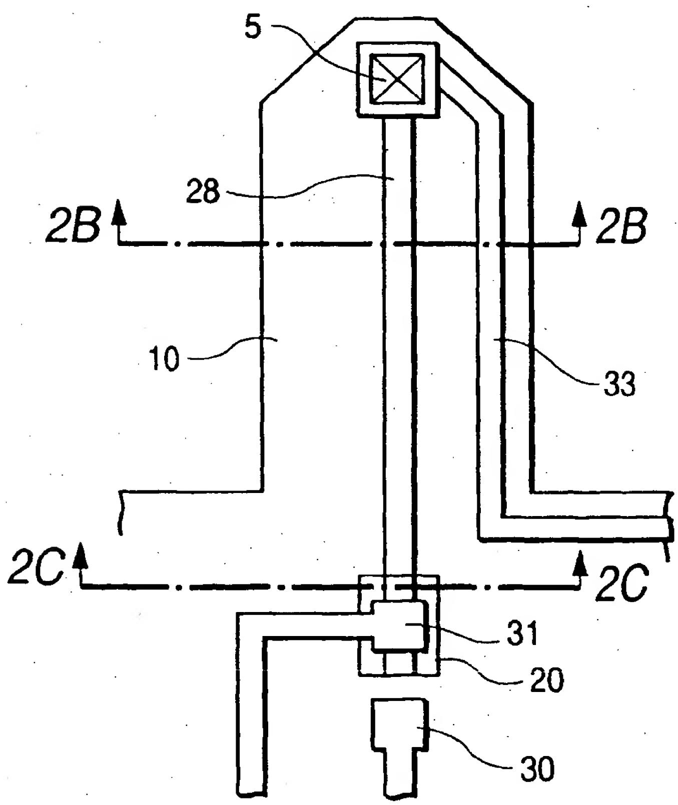


FIG. 2B

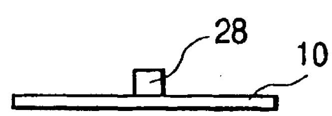


FIG. 2C

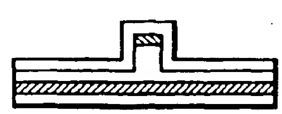


FIG. 4

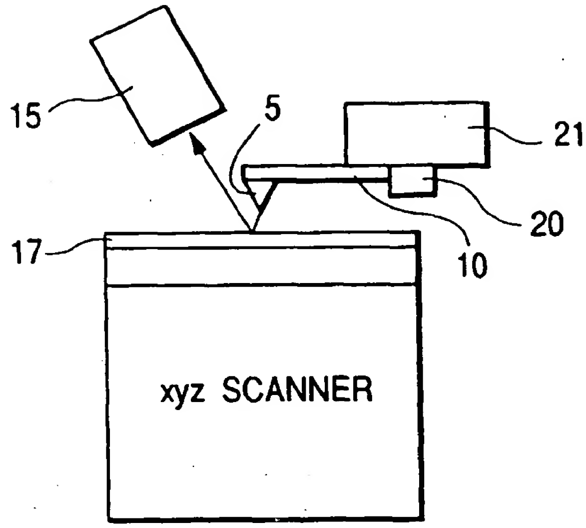


FIG. 5

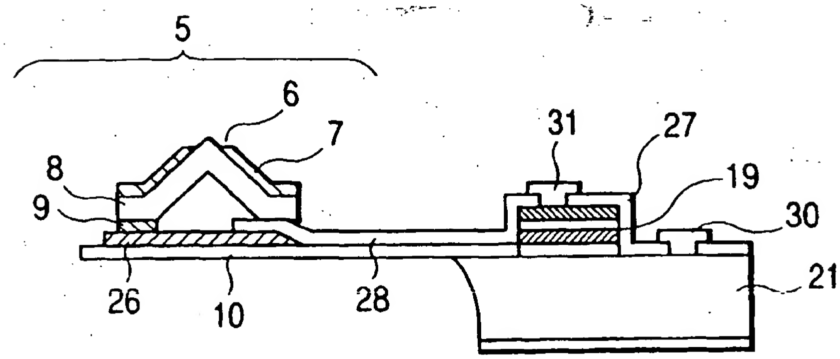


FIG. 7

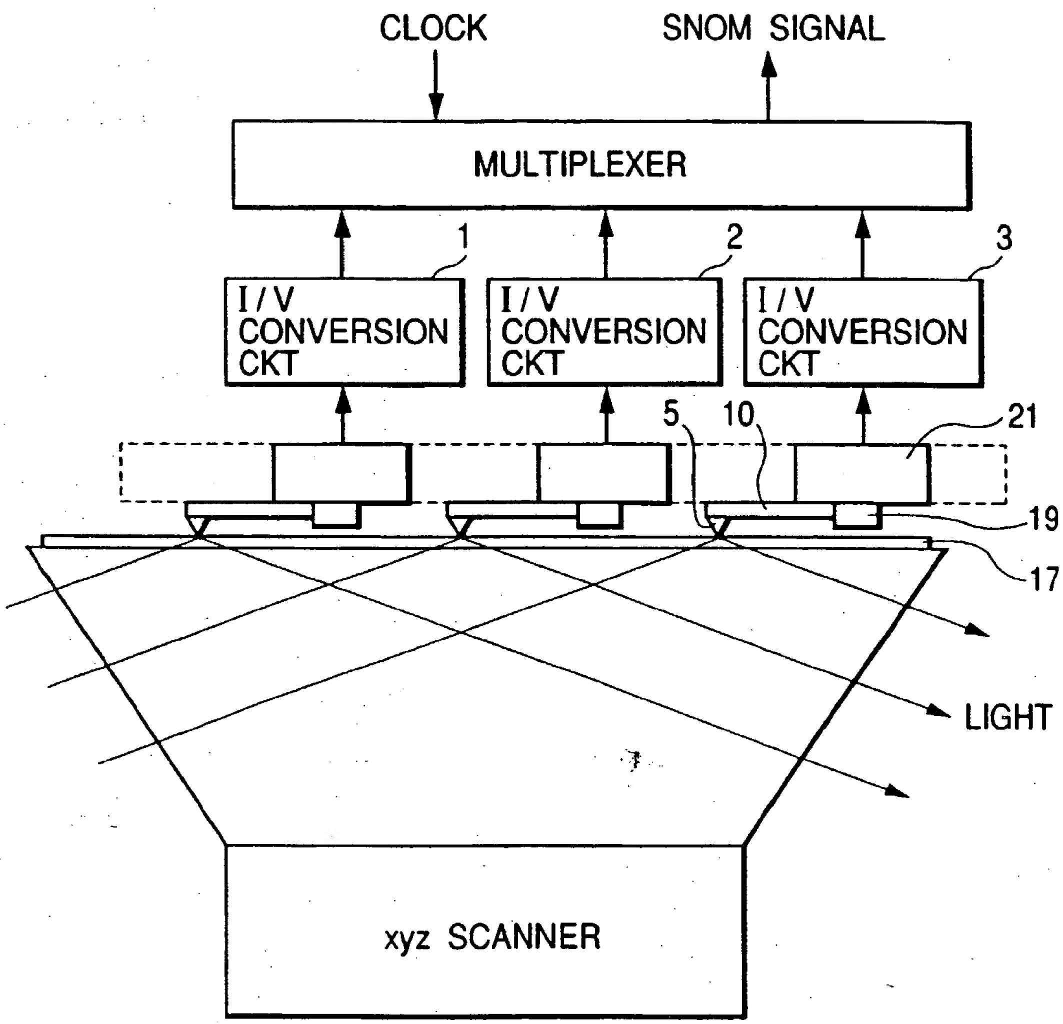

CLOCK
SNOM SIGNAL
MULTIPLEXER
1
2
3
I / V CONVERSION CKT
I / V CONVERSION CKT
I / V CONVERSION CKT
5
10
21
19
17
LIGHT
xyz SCANNER

FIG. 10A

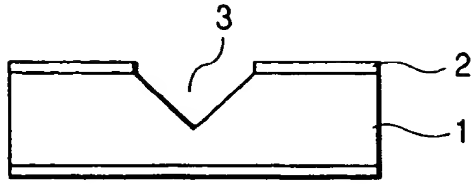


FIG. 10B

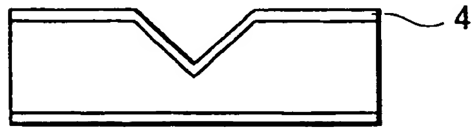


FIG. 10C

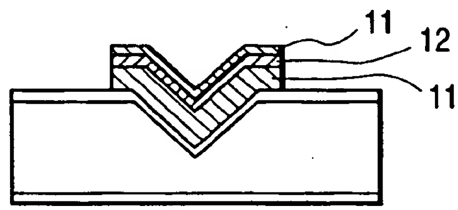


FIG. 10D

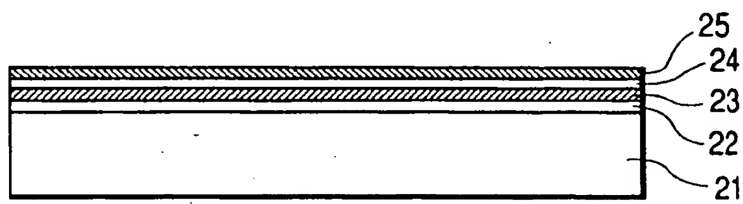


FIG. 10E

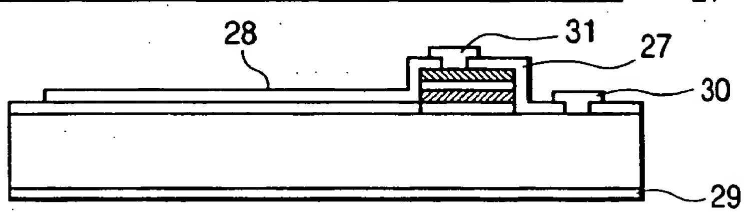


FIG. 10F

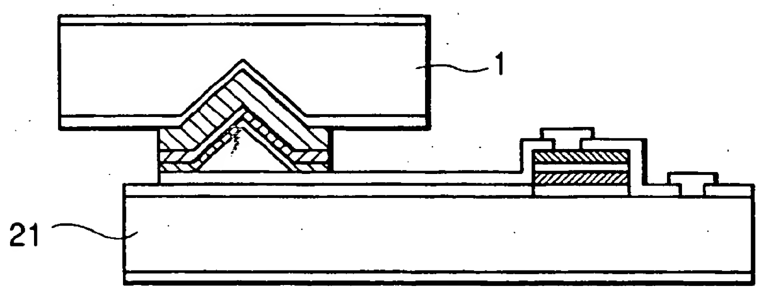


FIG. 10G

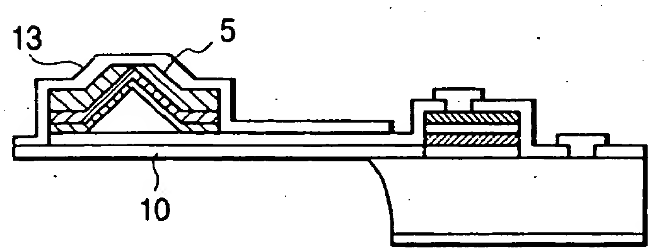


FIG. 12A

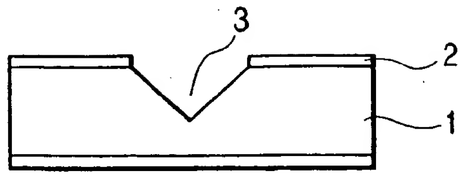


FIG. 12B

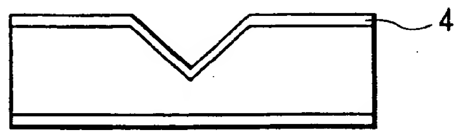


FIG. 12C

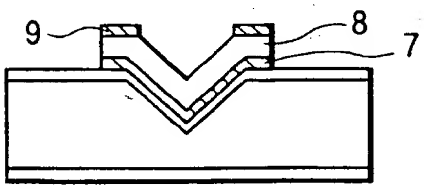


FIG. 12D

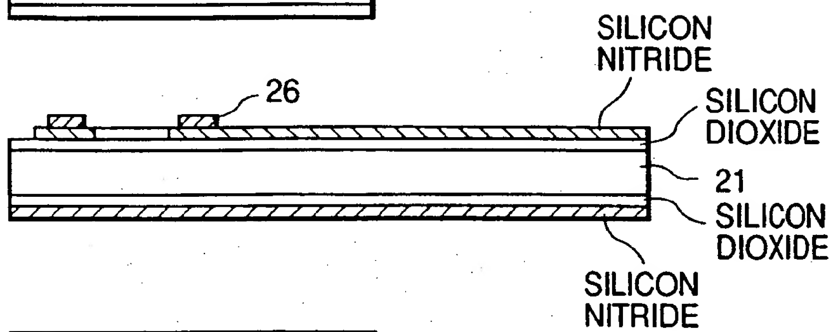


FIG. 12E

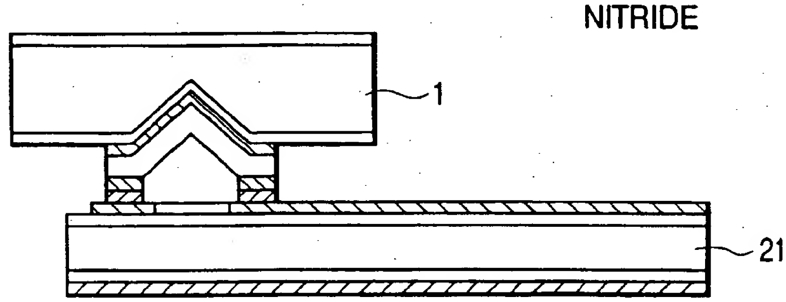


FIG. 12F

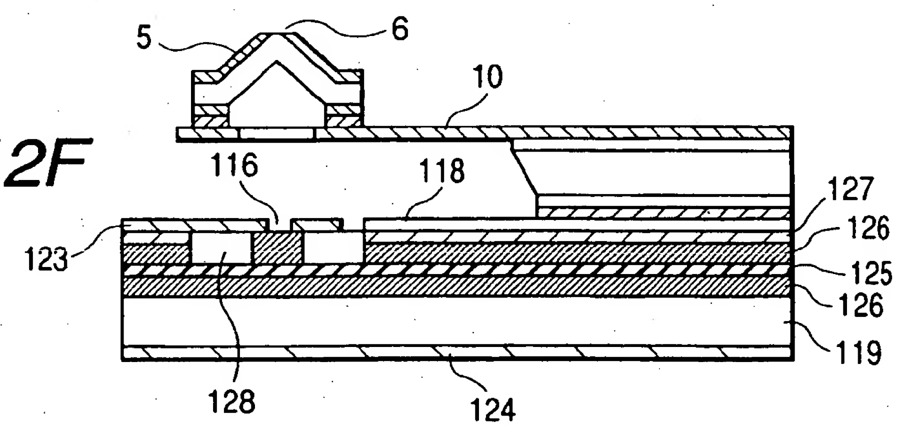


FIG. 14A
PRIOR ART

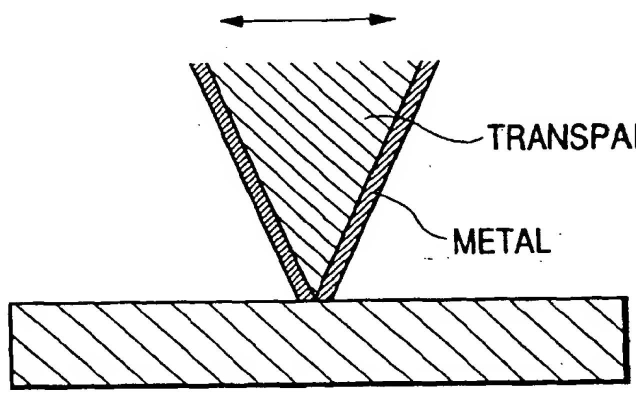
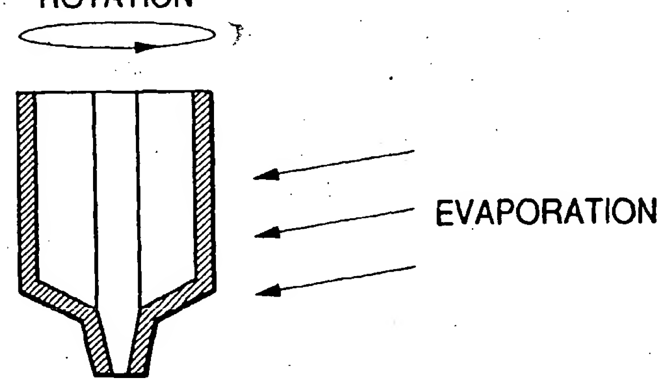


FIG. 14B
PRIOR ART



European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 10 2899

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,A	EP 0 112 402 A (IBM) 4 July 1984 * the whole document * -----	1-3,6,7,9	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	3 June 1998	Brock, T

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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